Worldwide Perspectives on Natural Gas Engines

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Gas Engines Worldwide

- **The use of gaseous fuels in IC engines is as old as the industry**
- **Although NG has many advantages as an IC engine fuel its suitability for mobile applications has always been limited by its storage density**
  - the total market size for NG engines is therefore orders of magnitude smaller than for liquid-fuelled engines
  - market size/potential sales has always governed R & D effort
- **Natural Gas is clearly the No. 1 gaseous fuel**
  - biogases (landfill & sewage), gasifier gases, mine and industrial process waste gases are all valuable, usable but minor sources
- **Power Generation (including DER with & without CHP) with IC Natural Gas engines matches a worldwide need**

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Natural Gas Worldwide

- **Vast resources have been identified, but the ability to exploit the potential applications of the fuel is uneven around the world**
  - in USA and Europe supply infrastructure and products to operate on the fuel are mature and highly developed
  - future sources of supply are influenced by both politics and economics

- **There is not a specific product called Natural Gas**
  - the variations in the composition of gases from different sources may have more significance for IC engines than most other ‘users’.
  - engine combustion settings to meet Power, Efficiency and Emissions requirements are very sensitive to gas composition
  - variable composition from a single supply is of greater concern than variations between regions
  - engine calibration settings can be adapted to suit, but true ‘on-line’ changes to wide composition changes is not yet a production reality

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Is the NG engine a natural choice for DER ?

- **Not really !**

- **The worldwide market for gas engines in the 1- 10 MW/unit class is increasing but slowly**
  - North America is the region with the largest market - due to national and local policy support ?
  - Central and SE Asia show significant growth, counterbalanced by falling opportunities in the Middle East

- **The environmental advantages of using NG are not in doubt**
  - emissions levels are not generally preventing sales (emissions have not driven the gas engine market in gas compression)
  - in some cases, however, the poorer efficiency and higher first costs of gas turbines are accepted, even in the 1-10 MW power range, to meet emissions targets
  - concern over the reliability/durability of IC engines has contributed to gas turbine sales

DER purchase decisions

- **Usually made on the basis of a rational capital investment appraisal, influenced by many factors including:**
  - 1st cost
  - running costs (maintenance costs, fuel cost, ηelec, ηthem)
  - Value of electricity and heat
  - projected life
- **Environmental issues are usually hurdles to get over, but benefits are increasingly being recognized as economically valuable**
- **Environmental and economic evaluations do, together, draw natural gas engines into contention for 1 - 10 MW/unit DER in all regions, not just in USA**
  - the European (& other) markets already place strong demand on thermal efficiency (fuel-to-electrical power conversion) and this will increase
  - Japan has very tough NOx limits in main cities and needs some DER

The Role of the US DOE

- The DOE initiatives are both vital and welcome !
  - They support the market and environmental needs
  - They offer funding in an area where cash has been scarce
  - They have followed EPA automotive initiatives by setting tough efficiency and emissions targets
    - the auto engine industry has responded well to such targets
  - They should help equip US products to compete better worldwide
    - US companies are also taking part in the trend to form worldwide groupings and associations

Research Capabilities

- **The most advanced research capabilities applicable to IC engine research can generally be found in US universities and national labs**
  - outstanding diagnostic, measuring and modeling work has been/is being done, relating to combustion and emissions formation/control
  - main application has been to the transient IC engine case
  - no other state or region could offer equivalent capabilities or skills in support of an IC engine advancement program

- **The US gas engine industry has perhaps not fully exploited these capabilities in the past**
  - new relationships and ways of working have to be fostered
  - mutual industry/academia skepticism is healthy - but can also be restrictive
  - **The industry should continue to observe and incorporate ideas, technologies and methodologies from overseas**

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Research Focus

- **There is sometimes a tendency to confine research thoughts to combustion and cycle optimization**
  - tribological and materials technologies have a part to play
  - thermal efficiency tends to be related to specific output, so increased unit mechanical and thermal loads have to be accommodated
  - minimum heat rejection to coolant and lubricant is likely to aid electrical generation efficiency

- **The largest paybacks will however probably come from combustion and cycle optimization or from improvements in reliability and maintenance costs**

- **The tools for all these include those advances mentioned earlier, from universities and labs, etc.**

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Gas Engine Technologies

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- **Flame propagation through premixed charges (loosely, Otto cycle - SI, μ-pilot or DF) has been the dominant combustion approach in gas-fuelled IC engines, for very practical reasons:**
  - **it was the only feasible system for most of the history of gas engines**
  - **it has significant low-NOx potential when lean mixtures are employed**
    - greater knock tolerance also results, allowing BMEP and Efficiency to be increased
- **Alternative combustion regimes are now under consideration**
  - **High Pressure Direct Injection of gas (HPDI)**
    - results in (mixing controlled) diffusion burning
    - high CR can be employed without Air/Fuel ratio control
    - high BMEP without any knock limitation
  - **Homogeneous Charge Compression Ignition (HCCI)**
    - results in very low NOx emissions

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Premixed Charge - with Flame Propagation

- Further improvement can yet be achieved with this Otto Cycle approach
  - **better ignition systems (including μ-pilot diesel ignition)**
    - will allow advances in dilution tolerance
  - **fuller application of kinetics models (e.g. GRIMech) with optimization of turbulence structures**
    - will describe best environment for ignition
    - will result in fast and more complete combustion of diluted charges
    - will enable role of EGR as a diluent to be better understood
      - combine with air or use EGR alone?
    - potential of EGR with Stoichiometric Charge can be more fully examined, for application of 3-Way Catalyst to give most complete emissions control
    - better mixture preparation & chamber design to reduce Knocking & Quenching
  - **Improved mixture preparation**
    - intensive application of CFD to gas and air flows in ports and cylinders
  - **improved sensing of combustion phenomena for control purposes**
    - also sensing of gas composition qualities upstream of engine metering system

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Premixed Charge Developments - current Worldwide Perspective

- **The benefits of μpilot ignition are seen in production engines from Japan and Europe (Niigata, MHI and Wärtsilä):**
  - higher BMEP and efficiency
  - improved reliability
  - less frequent servicing
- **Improvements to mixture preparation techniques, in both pre-chambers and main combustion chambers, published and promoted by Ricardo and then AVL**
- **Extension of open chamber ignition to larger engines in Europe:**
  - SI by Deutz (TBG 632 at 240 mm bore)
  - μpilot by Wärtsilä (W34G at 340 mm bore, - then larger)
- **Need for high turbocharging efficiency recognized and provided for mainly in Europe:**
  - ABB, MAN & MTU

HPDI

- This approach has been offered for ~10 years for large power generation engines by Wärtsilä (GD series)
  - **requires pilot injection of diesel fuel for ignition** (as for 'μ-pilot')
  - **demands gas at very high pressure for injection (3500-5000 psi)**
    - heavy power demand for compression
    - safety issues have expensive solutions
  - **delivers BMEP and thermal efficiency of a diesel engine, with very low particulate and reduced NOx emissions (cf. diesel)**
  - **very few sales !**   (price or emissions ?)
- North American work using LNG demonstrates reduced compression power requirement:
  - **Locomotive applications**
  - **Westport developments for smaller, lower cost engines, in demonstration phase. (Cummins/Westport Joint Venture etc.)**
- Limited future, due to need for significant de-NOx aftertreatment?

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HCCI

- **Still a research topic, - subject to great interest at present because of very low NOx formation, especially if mixture is diluted**
- **Possibilities for Automotive applications being considered most intensively at present**
  - Control over a rapidly changing speed/load matrix remains an issue- DER applications with mainly steady speed/load should be simpler to achieve good control of combustion
  - **Natural Gas may present a greater challenge for this type of operation, particularly where continuous operation at high loads is needed !**
  - requires very high temperature for autoignition, especially when lean enough to give low NOx
  - will result in high cylinder pressures
  - very sensitive to gas composition
- **Future heavily dependent upon good application of Kinetics modeling**
  - US exceptionally well-equipped to ‘pull this one off’

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AFTERTREATMENT

- **The quest for high efficiency probably ensures that IC engine-out NOx levels can never meet targets, with any combustion system**
  - de-NOx aftertreatment will become an integral part of the engine system
  - the automotive industry worldwide continues to stimulate ideas and research for NOx removal at an acceptable price
  - ideas & know-how for catalysis and other reaction technologies need to be 'tuned' for natural gas combustion products

- **The demands of low first cost will however still require lowest practicable engine-out emissions**

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Summary of The DoE IC Gas Engine Program, as viewed Worldwide

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- The appropriateness of a Governmentally supported gas engine development program to meet future DER requirements is generally accepted throughout the industrialized world to exploit benefits to national energy policy
- The market potential is firm enough for the engine and aftertreatment industries to invest cautiously but enough uncertainty remains to require enlightened governmental support
- Many technical challenges lie ahead for natural gas engines in DER applications and a well managed collaboration between industry and Government should bring mutual benefits to all

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